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Short-term choice behaviour in a mixed fishery: investigating métier selection in the Danish gillnet fishery

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The study presents a short-term effort allocation modelling approach based on a discrete choice random utility model combined with a survey questionnaire to examine the selection of métiers (a combination of fishing area and target species) in the Danish North Sea gillnet fishery. Key decision variables were identified from the survey questionnaire, and relevant proxies for the decision function were identified based on available landings and effort information. Additional variables from the survey questionnaire were further used to validate and verify the outcome of the choice model. Commercial fishers in a mixed fishery make use of a number of decision variables used previously in the literature, but also a number of decision parameters rarely explicitly accounted for, such as price, weather, and management regulation. The seasonal availability of individual target species and within-year changes in monthly catch ration were the main explanatory drivers, but gillnetters were also responsive to information on the whole fishery, fish prices, and distance travelled to fishing grounds. Heterogeneous responses were evident from geographic differences in home harbour, which underpins the need to understand alternative fishing strategies among individual gillnetters better.

Keywords: fisher behaviour, métier, mixed fishery, North Sea, random utility model.

Introduction

The importance of accounting for fisher behaviour when developing more efficient fisheries management regulations has long been realized (Wilen, 1979; Branch *et al.*, 2006). Notably, a concern has been the narrow focus on biological processes, disregarding the responses of fishers to changes in resource availability, market conditions, and management regulations (Hilborn and Walters, 1992; Salas and Gaertner, 2004; Hilborn, 2007). Since the early 1990s, more studies have focused on fleet dynamics or fisher behaviour, particularly about the allocation of fishing effort (Branch *et al.*, 2006). How fishers decide to allocate fishing effort can be scaled as either (i) long-term changes (year-to-year scale) in total fishing effort (or capacity), often matched by decisions to enter, stay, or exit a fishery, or (ii) short-term scale changes from a monthly to a trip-by-trip level, including decisions on when, where, and what to fish (Hilborn, 1985; Salas and Gaertner, 2004). Some studies have developed predictive models for both short-term (trip-by-trip scale) and long-term (year-to-year scale) behaviour in fisheries (see reviews in Salas and Gaertner, 2004; Branch *et al.*, 2006; Hilborn, 2007). Among potential options available for investigating short-term behaviour where a fisher/skipper is confronted with a finite set of alternatives (such as choice of fishing ground, target species, or gear), discrete choice random utility models (RUMs) are a flexible and useful functional approach (Wilen *et al.*, 2002; Reeves *et al.* 2008). Such methods have been applied widely in analyses of fisher choice of location (Campbell and Hand, 1999; Wilen *et al.*, 2002; Hutton *et al.*, 2004), choice of gear (Bockstael and Opaluch, 1983; Eggert and Tveteras, 2004), and choice of target species (Pradhan and Leung, 2004; Curtis and McConnell, 2004; Vermard *et al.*, 2008), but only a few studies have investigated the combined choices of fishing ground, gear, and/or target species (Holland and Sutinen, 1999; Marchal *et al.*, 2009). This is an important issue in mixed fisheries, where several species are caught in the same area with different gears, and the exploitation pattern for a stock arises from the combination of the three choice parameters: fishing ground, gear, and target assemblage. This combination can be referred to as a métier (Biseau and Gondeaux, 1988; EC, 2008; Ulrich *et al.*, 2009).

Commercial fishing is an economic activity, and it is traditionally assumed that fishers act rationally in terms of maximizing their profit/utility (van Putten *et al.*, 2011). In most fisheries, short-term behavioural decisions are made in an environment with uncertainty, where the fisher does not know how all the stocks are distributed and where the greatest utility/profit is obtained (Mangel and Clark, 1983). Instead, fishers attain knowledge of the profitability of the resources by using whatever information is available, e.g. catch success of other fishers, expected cost, available technology, past fishing success and patterns, tradition, availability of stocks, and management regulations, when attempting to maximize their expected utility (Hilborn and Walters, 1992; Salas and Gaertner, 2004). The importance of specific decision parameters varies among fisheries, and appropriate formulation of fisher expectations of maximizing utility and the associated uncertainty is critical when evaluating or testing behaviour hypotheses for individual fisheries (Smith, 2000; Wilen, 2004). What is common for most quantitative behavioural analyses of commercial fishers is that the formulation of a decision function is either constructed on theoretical economic theory or knowledge in the literature, and few studies have asked fishers or skippers directly how they construct and evaluate their expectations, e.g. via interviews (Holland and Sutinen, 1999; Salas *et al.*, 2004; Abernethy *et al.*, 2007). Another critical issue in modelling fisher behaviour is that many of the main factors influencing fisher choice are usually not available in traditional catch-and-effort databases; instead, proxies need to be formulated from available fisheries data to reflect the key decision variables (Smith, 2000). The purpose of this study is therefore to provide insights into fisher métier choices on a trip-by-trip scale in a mixed demersal fishery in the North Sea, combining qualitative and quantitative information. An analytical behavioural approach is applied based on the combined use of qualitative information from a large socio-economic survey questionnaire and an empirical RUM approach using official landings and effort information. Interview output is used to identify the decision parameters to include in the RUM, and qualitative ranking of these decision parameters by fishers is compared with quantitative ranking obtained as part of the output of the RUM.

The Danish North Sea gillnet fishery and management regulation

The Danish gillnet fleet is one of the main components of the mixed demersal fleet operating in the North Sea. Although the fleet has reduced in number since the mid-1990s, gillnetters in 2005 still contributed about half the Danish annual cod quota and ~30% of the total annual Danish landings (in value) of demersal species in the North Sea. Most North Sea gillnet vessels are based at Hirtshals, Hanstholm, Thyborøn, or Hvidesande, ports of the west coast of Jutland (Figure 1).

Danish North Sea gillnetters target a range of demersal fish: cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), saithe (*Pollachius virens*), hake (*Merluccius merluccius*), plaice (*Pleuronectes platessa*), sole (*Solea solea*), and turbot (*Psetta maximus*). Gillnets tend to be more species-selective than trawls, and gillnetters often target a single species at a time (Ulrich and Andersen, 2004).

The Danish North Sea gillnet fishery is regulated by a combination of quotas, technical measures, and since 2003, effort restrictions set annually by the European Commission. Before 2007, the seasonal allocation of the Danish quota for most demersal stocks was through a catch-ration system, the national regulatory committee assigning a catch ration (weekly, bimonthly, or monthly) for a given stock. The ration system was in principle open for all vessels, the ration size depending on the vessel size, but not the gear type. Rations were adjusted throughout the year to ensure a regular distribution of fishing opportunities, and relative changes in ration size were the same over vessel-size categories. In 2007, individual transferable vessel quotas were implemented in the Danish demersal fishery, so the most recent years are not considered here.

Survey questionnaire

A survey questionnaire on tactical and strategic decision processes of the entire Danish demersal fleet was conducted in 2004 (Christensen and Raakjær, 2006), 789 questionnaires being circulated and 271 being returned (34% of fishers).The survey was divided into two steps, a qualitative in-depth and semi-structured interview with 16 fishers (of which five were North Sea gillnetters), and a questionnaire based on the information obtained from the interviews. Each fisher was interviewed in sequence (up to three times) during a 2-month period, to obtain a thorough and detailed understanding of the situation of each and to cover all relevant aspects. The results from the questionnaire provided detailed qualitative information on the tactical decisions of fishers in terms of choice of fishing ground, target species, and gear. Eight essential factors in the choices made were identified (ranked by level of importance): (i) present situation (own experience from recent trips), (ii) season/time of year, (iii) regulations, (iv) fish prices, (v) weather (wind and currents), (vi) distance to fishing ground, (vii) information from other fishers, and (viii) fuel cost. The level of importance of each was ranked from 1 to 4 by the informant, 1 categorized as not important, 2 as less important, 3 as important, and 4 as very important. A ranking system of four categories allows importance levels to be differentiated and avoids neutral statements having to be defined with an uneven number. Pilot testing of the questionnaire showed that four categories are plenty for fishers (see detailed descriptions of the survey questionnaires in Christensen, 2009). For the present study, data covering North Sea gillnetters >12 m were extracted (54 fishers) and used to frame the structure of the subsequent quantitative discrete choice model, described below.

Fishery data

Quantitative modelling was based on catch and effort at a trip level drawn from official logbooks, sales slips, and vessel register data. The dataset was restricted to vessels from the four fishing ports (above) with annual revenues of a minimum €37 000. This criterion was set to exclude vessels that were either part time or not fully active (Andersen *et al.*, 2005). Danish North Sea gillnetters operate almost solely with gillnets, only a few (~5% of gillnet vessels) fishing occasionally also with lines or pots. Those vessels have been excluded to preclude additional complexity in the behaviour model. Trips where no information on own experience from the previous month or year existed were also excluded. For those métiers where no observations on the catch rate (value landed per fishing day), effort, or both had been recorded over a period, the same assumption was used as Marchal *et al.* (2009), assuming that the underlying reason for no fishing activity was that the fishing activity was unattractive. To fill in empty cells, we used the overall lowest observation (catch rate or effort) for that period. In all, 7541 fishing trips,

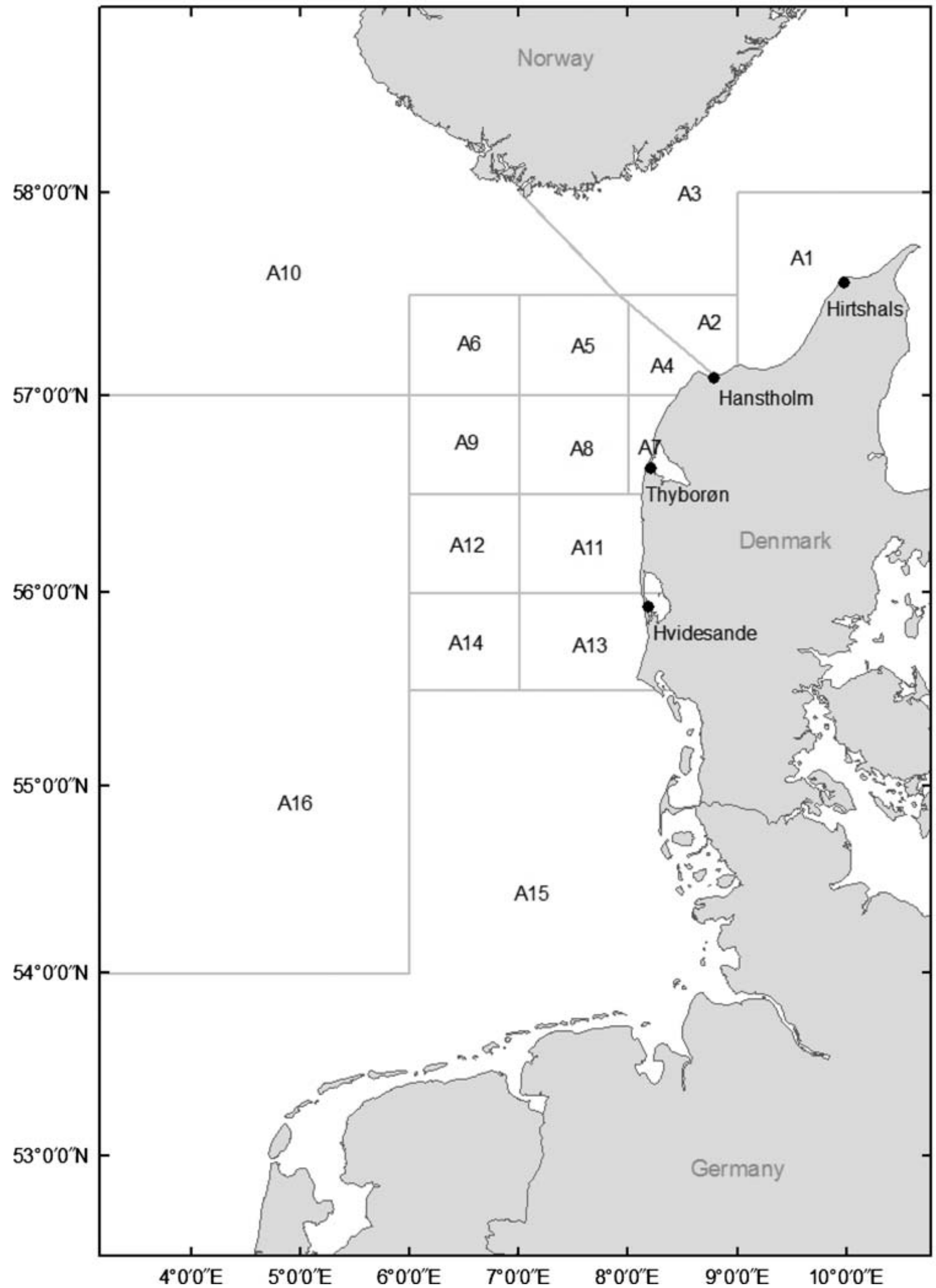

Figure 1. Map of defined fishing areas and the positions of the main fishing ports for the Danish North Sea gillnet fleet.

undertaken by 72 vessels in 2003, 2004, and 2005, were included in the final dataset.

Defining the choice set

Fishing activities in mixed fisheries on a trip basis can be characterized by the gear used, alternative rigging specifications (e.g. mesh size), fishing ground, and/or target species (Pelletier and Ferraris, 2000). Different combinations of these three variables are referred to as métiers, which are assumed to reflect the decision made by fishers before each fishing trip. The definition of métiers in terms of Danish gillnetters operating in the North Sea given by Ulrich and Andersen (2004) was updated and modified for consistency with multivariate analytical approaches applied to identify métiers in mixed fisheries (Pelletier and Ferraris, 2000; ICES, 2003; Ulrich and Andersen, 2004; Table 1). Ulrich and Andersen (2004) noted that mesh size alone could not discriminate among different gillnetting métiers, because nets with different mesh size can be laced together. Moreover, material and rigging equipment, which is not reported in logbooks, plays a key role in gear selectivity in terms of target species,

Table 1. Danish gillnetting métiers in the North Sea, where the definition of métiers is based on a hierarchical cluster analysis from 2003 to 2005, showing for each métier (or defined cluster) the mean and minimum (in parenthesis) proportion of the main species (emboldened) in the landing assemblage and number of trips.

Métier	Number of trips	Cod	Plaice	Sole	Turbot	Other
Plaice	1 629	0.048	**0.779 (0.45)**	0.065	0.049	0.059
Cod	3 790	**0.899 (0.44)**	0.021	0.007	0.007	0.066
Sole	2 092	0.039	0.162	**0.727 (0.11)**	0.036	0.036
Other	2 861	0.312	0.161	0.024	0.053	**0.451 (0.0)**
Turbot	366	0.026	0.027	0.011	**0.845 (0.49)**	0.091

so landings profiles were considered an appropriate proxy for choice of rigging.

The greatest spatial resolution of available fishery data for Danish gillnetters was ICES rectangles (~30 × 30 nautical miles at this latitude), but using this level of spatial resolution in the behaviour model would lead to a complex model structure because of the large number of choice alternatives (Hutton *et al.*, 2004). To reduce the spatial dimension of the model, therefore, we condensed the total number of ICES rectangles (84) to 16 fishing areas by aggregating rectangles less frequently visited (<100 observations) with neighbouring rectangles, as shown in Figure 1. Combining target species and fishing areas resulted in a total of 62 métiers with catch-and-effort information, which defined the final set of alternative choices available to individual gillnetters during the period studied.

Empirically modelling métier choice

A discrete choice RUM approach was applied to model métier choice. The underlying assumption in the approach is that a decision-maker (fisher or fishing vessel), n, always chooses the alternative, i, that maximizes his utility, U_{ni}. The utility is expressed by a set of explanatory variables that are summarized to form a systematic or observable component V_{ni}, and an unobservable stochastic error component ϵ_{ni} (random part):

$$U_{ni} = V_{ni} + \varepsilon_{ni}. \quad (1)$$

The probability of a fisher n choosing a particular alternative i can be described by

$$P_n(Y=i) = P_n(U_{ni} > U_{nj}) \Rightarrow P_n(Y=i) = P_n((V_{ni}+\varepsilon_{ni}) > (V_{nj}+\varepsilon_{nj})) \quad \text{for all } i \neq j, \quad (2)$$

in which the assumption of the random component ε (or measurement error) can lead to different types of the discrete choice model (Train, 2003). Two aspects of the structure of the choice model are investigated, which explanatory variables have a significant effect on choice behaviour, and whether choices of fishing ground and target species are made simultaneously (non-nested) or as a nested structure, where fishing ground is chosen before target species, or vice versa (Figure 2).

Model parametrization

To estimate the probability in Equation (2) in its simplest form, it is assumed that the random component, ε_{ij}, in Equations (1) and (2) is independent over choices, and identically distributed with an extreme value distribution $[F_{(\varepsilon_{ni})} = \exp(-e^{\varepsilon_{ni}})]$. If this is the case, the probability of choosing a métier i can be expressed by a

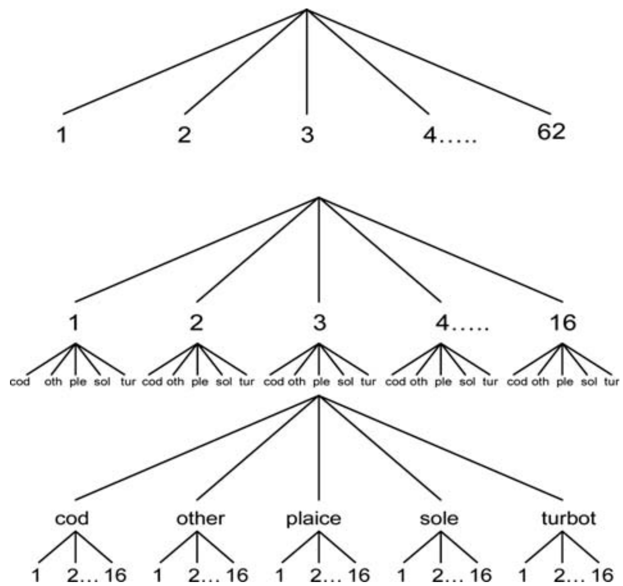

Figure 2. Decision tree for the three model structures applied. Upper panel, non-nested; centre panel, nested N1 (area–species); lower panel, nested N2 (species–area).

conditional logit model (Mcfadden, 1974):

$$P_{ni} = \frac{e^{V_{ni}}}{\sum_j e^{V_{nj}}} = \frac{e^{\beta X_{ni} + \alpha_i W_n}}{\sum_j e^{\beta X_{nj} + \alpha_i W_n}}, \quad (3)$$

where data can consist of choice-specific attributes, X_{ni}, that vary over choices and characteristics, W_n, of the individual (or groups) of the population that do not vary over choices. A problem with the conditional logit lies in the restrictive assumption of independence of irrelevant alternatives (IIA; Train, 2003), i.e. that any changes in the attributes of one choice require proportional changes in the probability associated with alternatives. Wilen *et al.* (2002) pointed out that the assumption of IIA is often violated in the context of fishery management, because some alternatives share the same unobserved characteristics.

The conditional logit can be generalized in several ways explicitly to relax the assumption of IIA and to account for heterogeneous correlation structure among both alternatives and decision-makers (Hensher *et al.*, 2005). An alternative is to apply nested logit models to commercial fisheries (Morey *et al.*, 1993; Holland and Sutinen, 1999; Wilen *et al.*, 2002; Marchal *et al.*, 2009). Nested logit models partition the choices into different branches, the random error component allowing alternatives within a branch to be correlated. This means that a nested logit model maintains the IIA assumption for choices within the same branch, but relaxes it for choices across branches. This is undertaken by assuming that decisions are taken sequentially following a nested decision structure. In our case, either fishing ground would have been chosen before target species, or vice versa (Figure 2). In a nested model, the utility for choosing a given alternative i is expressed as $U_{ni} = Z_{nk} + Y_{ni} + \epsilon_{ni}$, where Z_{nk} are the parameters in the first-level utility function in branch k, and Y_{ni} are the parameters in the second-level utility function.

The probability of choosing alternative i in a nested design can be expressed as the product of two standard logit models (Train, 2003):

$$P_{ni} = P_{ni|B_k} P_{nB_k}, \text{ where } i \in Bk, \tag{4}$$

where $P_{ni|B_k}$ is the conditional probability of choosing alternative i given that alternative i is in branch B_k, and $P_{nB_k}$is the probability that branch k is chosen. $P_{ni|B_k}$ and P_{nB_k} are expressed as

$$P_{ni|B_k} = \frac{e^{Y_{ni}}}{\sum_{j \in B_k} e^{Y_{nj}}}, \tag{5}$$

$$\text{and } P_{nB_k} = \frac{e^{Z_{nk} + \lambda_k I_{nk}}}{\sum_{\ell=1}^{K} e^{Z_{n\ell} + \lambda_\ell I_{n\ell}}}, \quad I_{nk} = \ln \sum_{j \in B_k} e^{Y_{ni}}, \tag{6}$$

where I_{nk} is the inclusive value of branch k, and λ_k is the inclusive coefficients (or dissimilarity coefficients) of I_{ni} parameters. The value $1 - \lambda_k$ is the correlation among unobserved components in the nested utility function, and it captures the extent of correlation among alternatives within a branch (Train, 2003). The closer λ_k is to zero, the greater the correlation among alternatives within a branch. In general, the inclusive coefficients should fall between 0 and 1 (Train, 2003).

Decision parameters

The observed utility function in Equation (1) was based mainly on the parameters identified in the questionnaire survey. However, transformation of qualitative decision parameters into a useful quantitative format was not straightforward. The problem is that many decision parameters are not directly accessible from logbook and sales-slip information, so must be replaced by proxies (Smith, 2000). For each of the eight parameters identified in the questionnaire, we defined an appropriate proxy based on data readily available.

Information from other fishers

It is usually considered that catch information from other fishers is a key economic behavioural driver (Salas and Gaertner, 2004; Wilen, 2004), and recent catch success of other fishers (catch weight or monetary value) has often been used as a proxy for expected profitability. Various types of catch expectation model have been applied, ranging from simple approaches, such as summing the total value or estimating the average value for the fleet (Bockstael and Opaluch, 1983; Vermard *et al.*, 2008) to more sophisticated production function models, in which individual vessel characteristics are taken into account (Holland and Sutinen, 1999). Here, we assume that a fisher obtains recent catch information from other fishers, expressed as average revenue per unit of effort (RPUE) of the landings from the previous month for the Danish North Sea gillnet fleet. We assume perfect knowledge transfer across the fleet. RPUE is defined as the product of landing price per kilogramme and landings (kg) per day at sea. To account for differences in vessel characteristics (e.g. size and engine power and skipper skills), RPUE was standardized using a generalized linear model (Gavaris, 1980; Vignaux, 1996):

$$\text{Log(RPUE)}_{nym} = Y_y + M_m + \text{ves\_id}_n + \varepsilon_{nym}, \tag{7}$$

where RPUE is the revenue landed for each vessel n per month M of year Y. The error component is assumed to be normally distributed. The Y (year) and M (month) terms cover the variations in resource availability, and the ves_id term describes a vessel characteristic relative to other vessels in the gillnet fleet. The standardization parameters were estimated separately for each of the five target species.

An alternative way to collect information of other fishers' exploration patterns is to use the spatial distribution of vessel density. With the introduction of electronic equipment (GPS-linked to locality notification of other vessels), fishers can easily locate other vessels. Vignaux (1996) observed that the New Zealand purse-seine fleet had a tendency to move to areas where other vessels were fishing, expecting better catch success in those areas. We used total effort by area from the previous month (TOT_EFFORT) as a proxy for vessel aggregation.

Risk

Uncertainty was not explicitly highlighted in the survey questionnaire, but because fishers are exposed to various levels of uncertainty, they may either behave as risk-seekers that explore areas with high uncertainty, expecting extra-high payoffs, or be risk-averse, preferring to minimize risk by searching for alternatives with a more stable payoff (Mistiaen and Strand, 2000; Eggert and Tveteras, 2004). The coefficients of variation (*CV*) of the RPUE from the previous month (*CV* of RPUE) were used as proxies for risk behaviour, consistent with those studies.

Own experience

A fisher's experience can be split into present and seasonal knowledge/experiences. Danish gillnetters usually make several trips per month and accumulate experiences/knowledge for each location they visit. Typically, trip duration is 1–2 d (>75% of trips), but a few last up to 5–7 d (<8%). We chose to use the percentage of effort each fisher devoted in each alternative choice during the previous month as a proxy for the relative level of experience a fisher had recently obtained from the alternatives visited during the previous period (PRESENT_EXP). Questionnaire information showed that Danish gillnetters tended to follow a seasonal pattern and that the percentage of effort allocated to each métier choice in the previous year and period could be used as a proxy for the seasonal availability of resources (SEASON_EXP).

Fuel cost/distance

As information of fuel cost at a trip level are rarely available, distance has traditionally been used as a proxy for fuel cost (Sampson, 1991; Holland and Sutinen, 1999; Wilen *et al.*, 2002). In the questionnaires, fuel cost and distance were separated as two distinct decision factors. However, because of the strong correlation between the two (Christensen and Raakjær, 2006), they were condensed into a single proxy (DISTANCE), calculated as the distance from departure harbour to the fishing ground (centre of the ICES rectangle, 1 unit = ~30 miles).

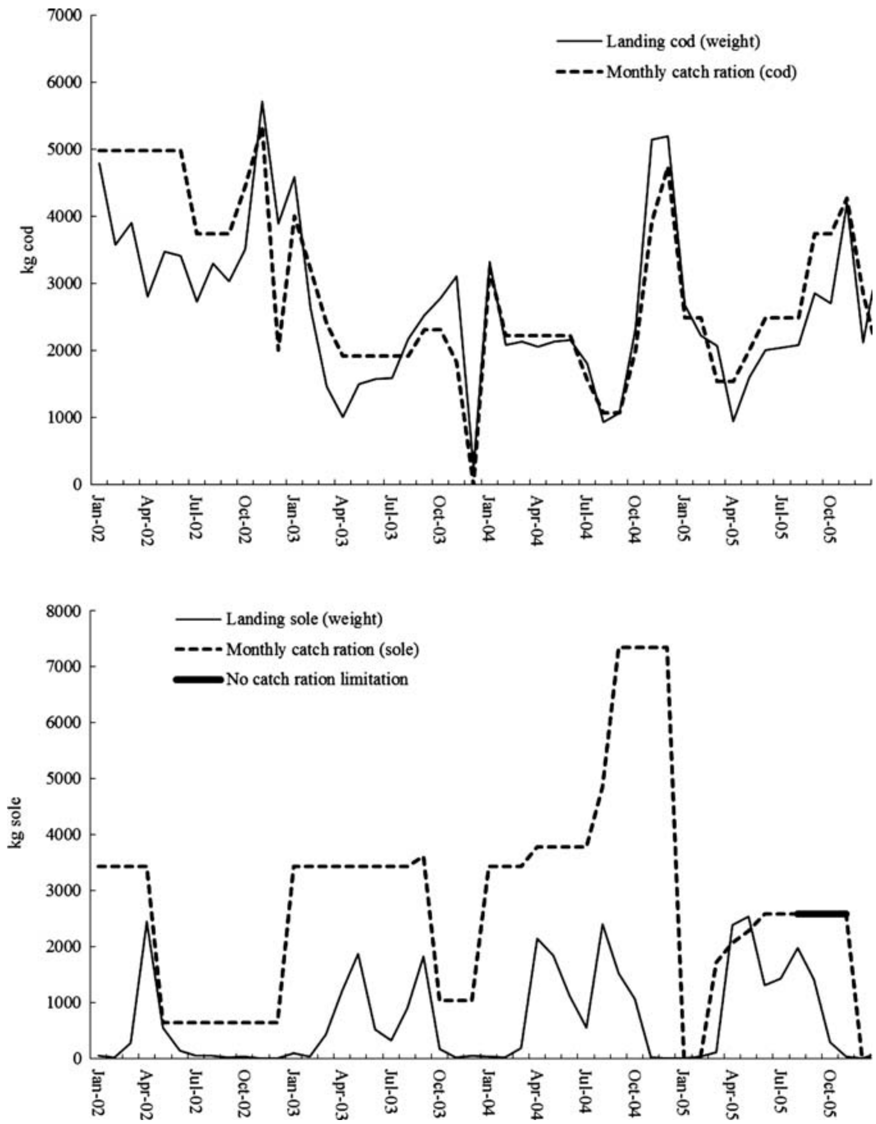

Figure 3. Seasonal allocation of monthly ration of and average landings by Danish gillnetters for (upper panel) cod, and (lower panel) sole in the North Sea, 2003–2005.

Regulations

We focus here on the regulatory mechanisms that influence fisher choice of métier on a trip-by-trip basis. In the reference period (2003–2005), seasonal catch restriction in terms of monthly catch ration was the main regulatory mechanism influencing the expected profitability in terms of fish stocks to target (REGULATION). Historical information on the landing ration was collected from the national fishery organization's weekly newspaper, in which all changes in regulations are recorded and linked to trips in the catch-and-effort database. Annual TACs for cod and sole in the North Sea declined during the study period owing to low stock biomasses (ICES, 2006), resulting in dramatic but transitory fluctuation in monthly catch rations for both species (Figure 3). For the other target species, no noticeable restriction was enforced, so these species were assumed to be unrestricted in the model.

Weather

Gillnetters are relatively sensitive to the weather because of the small vessel size and reduced manoeuvring possibility when setting nets in poor conditions. Wave height was used as a proxy for rough weather (WEATHER). Daily information on wave height in each area was obtained from the Danish Meteorological Institute's (DMI) wave-forecasting service (see Günther *et al.*, 1992, for detail).

Fish price

For each target species, the average price per kilogramme (PRICE) was computed monthly from sales slips available in the Danish logbook database. Variability of price was small among fishing areas and main landing harbours, so prices were assumed to be constant across both.

Combination of parameters

All these decision parameters were combined into the expected utility function as follows:

$$V_{ni} = \beta_1 \,\mathrm{RPUE} + \beta_2 \,CV \,\mathrm{of\,RPUE} + \beta_3 \,\mathrm{TOT.EFFORT} + \beta_4 \,\mathrm{PRESENT.EXP} + \beta_5 \,\mathrm{SEASON.EXP} + \beta_6 \,\mathrm{DISTANCE} + \beta_7 \,\mathrm{WEATHER} + \sum_{tg=1}^{tg=6} \alpha_{tg} \,\mathrm{REGULATION}_{cod(N)} + \sum_{tg=1}^{tg=6} \alpha_{tg} \,\mathrm{REGULATION}_{cod(S)} + \sum_{tg=1}^{tg=6} \alpha_{tg} \,\mathrm{REGULATION}_{sole} + \sum_{tg=1}^{tg=5} \alpha_{tg} \,\mathrm{PRICE}_{cod} + \sum_{tg=1}^{tg=5} \alpha_{tg} \,\mathrm{PRICE}_{plaice} + \sum_{tg=1}^{tg=5} \alpha_{tg} \,\mathrm{PRICE}_{sole} + \sum_{tg=1}^{tg=5} \alpha_{tg} \,\mathrm{PRICE}_{turbot}, \quad (8)$$

where the characteristics of an alternative are based on the five identified target species, tg (cod, other, plaice, sole, and turbot). Although the cod in the North Sea and Skagerrak are considered as a single stock in assessment (ICES, 2006), separate monthly catch rations are provided for the two areas. Therefore, we separated cod into cod(N) and cod(S), giving a total of six stock categories. There was no difference in the average price per kilogramme for cod in the North Sea and Skagerrak, so further distinction for price was not needed. For each characteristic, a target species was set as the reference category, and all parameters were estimated relative to that (Agresti, 2002). For nested logit models (N1 and N2), all parameters were estimated in the second level of the utility function.

Evaluating model output

To measure how well the models fitted the data, a likelihood ratio index (or McFadden pseudo-R^2) and χ^2 statistics for statistical comparison of different model settings (Train, 2003) were used. Additionally, the predictive power of each model was tested by comparing the estimated probability with observed data for the whole period.

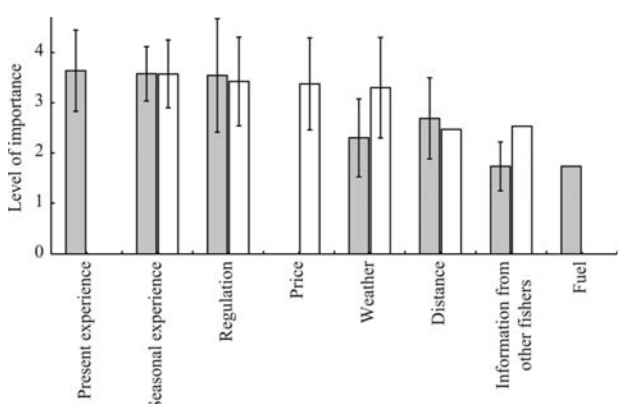

Figure 4. Mean ($\pm$ s.e.) scores from a survey questionnaire (54 observations) of Danish North Sea gillnetters. See text for further detail, but ordered from left to right based on the level of importance.

To evaluate the explanatory power of individual variables in the choice models, a simple backward elimination method was used, starting with the full model, then excluding the variable with the highest *p*-value, then refitting the model again until all predictors were excluded (Sokal and Rohlf, 1995).

Results

Analysis of the questionnaire data

Own (present) experience, seasonal experience, weather, price, and regulation were of major importance for the choice of fishing ground and target species by Danish North Sea gillnetters, and information from other fishers, distance, and fuel cost were less important (Figure 4). All eight parameters were used to define the explanatory variables in the utility function of the discrete choice models.

Global fit between models

The pseudo-R^2 values were relatively similar for the three discrete choice models [conditional (non-nested) model, nested N1 (area–species), and nested N2 (species–area)], values ranging from 0.45 to 0.48 (Table 2). Non-nested were tested against nested models by setting all inclusive values equal to 1 ($H_{0(N1)}$: $\tau_{1,\ldots,16} = 1$ or $H_{0(N2)}$: $\tau_{1,\ldots,5} = 1$), which transformed the nested logit model into a standard conditional logit model. For both nested logit models, the hypotheses of inclusive values equal to 1 was rejected ($H_{0(N1)}$: $\chi = 45.78$, $p < 0.001$; $H_{0(N2)}$: $\chi = 34.45$, $p < 0.001$), implying that the IIA assumption failed for the conditional logit model, although the global fit and parameter estimates were similar between nested models and the conditional logit model.

To evaluate which decision structure was most appropriate among the two nested models, the extent of correlation among alternatives within a nest was evaluated. For both nested models (N1 and N2), the inclusive values were positive, but for the nested-N1 model, all inclusive coefficients were slightly above 1; this was not the case for the nested-N2 model. Train (2003) stressed that $0 < \lambda \leq 1$ was a necessary and sufficient condition with the assumption of utility maximization, whereas Herriges and Kling (1996) stated that $1 < \lambda < 2$ would usually not fail to meet the underlying assumption within utility maximization of the models. Inclusive values >1 imply greater correlation among alternatives of different branches than among the alternatives within the same branch. In the nested structure (N1) with area in the upper branch, an inclusive coefficient >1 indicates that a target species is a better substitute for the same target species in another area. With all inclusive coefficients for area significantly >1 and several >2, the indication is strong that target species is not area-specific, and it is uncertain whether this nested structure (N1) captures the nature of substitutability among alternatives. Based on this uncertainty, we chose to use the nested-N2 model in subsequent tests for heterogeneous responses among groups of fishers.

Estimated coefficients

The sign and the value of the estimated decision coefficients were similar for the three RUMs. However, there were differences among the coefficients of effort and weather, which were significantly higher and lower than zero, respectively, in the conditional and nested-N2 models, but not significantly different in the nested-N1 model. RPUE was significantly positive for all models, but contributed to just 6% of the variability explained in the

Table 2. Parameter estimates from the three logit models.

Parameter		Conditional logit model Estimate	s.e		Nested logit N1 (area-tg) Estimate	s.e.		Nested logit (N2) (tg-area) Estimate	s.e
Choice and vessel-specific parameters									
RPUE(t-1)		**0.00005**	0.00001		**0.00030**	0.00001		**0.00026**	0.00001
CV of RPUE		**0.00820**	0.00030		**0.00750**	0.00052		**0.01350**	0.00051
TOT_EFFORT(t-1)		**0.00371**	0.00042		0.00023	0.00037		**0.00397**	0.00040
PRESENT_EXPERIENCE(t-1)		**0.03420**	0.00050		**0.03080**	0.00048		**0.03460**	0.00049
SEASON_EXPERIENCE(t-12)		**0.03150**	0.00046		**0.02760**	0.00042		**0.03210**	0.00043
DISTANCE		**-0.22970**	0.01290		**-0.28610**	0.02050		**-0.33790**	0.01320
WEATHER		**-0.25480**	0.03610		-0.07110	0.04750		**-0.13320**	0.04220
REGULATION									
Cod(N) ration	cod(S)	**-0.00126**	0.00049		**-0.00272**	0.00038		**-0.00082**	0.00048
	other	**-0.00127**	0.00040		**-0.00185**	0.00043		-0.00097	0.00046
	plaice	**-0.00509**	0.00051		**-0.00606**	0.00046		**-0.00558**	0.00056
	sole	**-0.00556**	0.00054		**-0.00656**	0.00055		**-0.00472**	0.00061
	turbot	**-0.00524**	0.00148		**-0.00469**	0.00135		-0.00262	0.00141
Cod(S) ration	cod(N)	**-0.00129**	0.00049		**-0.00332**	0.00033		**-0.00125**	0.00045
	other	0.00074	0.00048		-0.00084	0.00039		0.00017	0.00045
	plaice	0.00042	0.00052		-0.00074	0.00046		0.00033	0.00056
	sole	**-0.00335**	0.00072		**-0.00410**	0.00035		**-0.00258**	0.00047
	turbot	**-0.00614**	0.00211		-0.00391	0.00153		-0.00095	0.00226
Sole ration	cod(N)	**0.00052**	0.00010		0.00004	0.00011		**0.00080**	0.00015
	cod(S)	**0.00080**	0.00013		**0.00054**	0.00014		**0.00106**	0.00019
	other	**0.00042**	0.00011		0.00012	0.00013		**0.00047**	0.00014
	plaice	**0.00058**	0.00012		0.00015	0.00013		**0.00080**	0.00016
	turbot	0.00051	0.00029		0.00003	0.00029		0.00045	0.00028
PRICE									
Price (cod)	other	**-0.40350**	0.13575		**-0.34575**	0.12225		**-0.42225**	0.13200
	plaice	0.20250	0.14400		-0.22800	0.12225		**-0.59550**	0.14625
	sole	-0.25500	0.16425		**-0.51975**	0.15450		-0.27675	0.16500
	turbot	**-2.12550**	0.49050		-0.40425	0.35550		-0.14325	0.56325
Price (plaice)	cod	**1.98075**	0.18675		**0.56625**	0.15375		**0.99075**	0.22200
	other	**1.12350**	0.19575		**-0.57375**	0.18375		-0.36525	0.20325
	sole	**3.05400**	0.18150		**1.62975**	0.16875		**2.05575**	0.22425
	turbot	**4.47375**	0.41700		0.44100	0.36675		0.85800	0.35400
Price (sole)	cod	**0.15000**	0.03289		0.05303	0.03266		**0.37125**	0.04897
	other	**0.41100**	0.03391		**0.43425**	0.03421		**0.59400**	0.04569
	plaice	**0.35025**	0.03519		**0.20400**	0.03191		**0.49950**	0.04465
	turbot	**0.45375**	0.07800		**0.33525**	0.06799		**0.36300**	0.09975
Price (turbot)	cod	0.15450	0.08250		0.05054	0.04306		0.15600	0.15150
	other	0.18000	0.08250		-0.00938	0.04549		0.14700	0.12525
	plaice	**0.42600**	0.08250		**0.24675**	0.04520		**0.43275**	0.13575
	sole	**0.43425**	0.08325		**0.30150**	0.04814		**0.38850**	0.11250
Inclusive value parameters									
				Area1	**2.95130**	0.15240	cod	**0.6837**	0.03400
				Area2	**1.80230**	0.06850	other	**0.9496**	0.03550
				Area3	**2.67060**	0.07870	plaice	**0.8912**	0.04030
				Area4	**2.62580**	0.07040	sole	1.0581	0.03800
				Area5	**1.31460**	0.13690	turbot	1.0621	0.06690
				Area6	**1.81540**	0.18140			
				Area7	**2.26940**	0.10160			
				Area8	**2.00030**	0.07060			
				Area9	**2.07130**	0.14800			
				Area10	**1.27700**	0.13520			
				Area11	**2.46020**	0.05760			
				Area12	**1.72430**	0.09070			
				Area13	**2.10250**	0.09050			
				Area14	**1.19940**	0.10110			
				Area15	**2.80750**	0.10260			
				Area16	**1.41810**	0.07500			
Global model fit									
Pseudo R^2		0.4497			0.4843			0.467	
Log Likelihood (restricted LL= -32558)		-1 7918			-1 6791			-1 7355	

Bold: H_0: $\alpha = 0$ or $\beta = 0$, $p < 0.01$; H_0: $\lambda = 1$ (inclusive value), $p < 0.01$

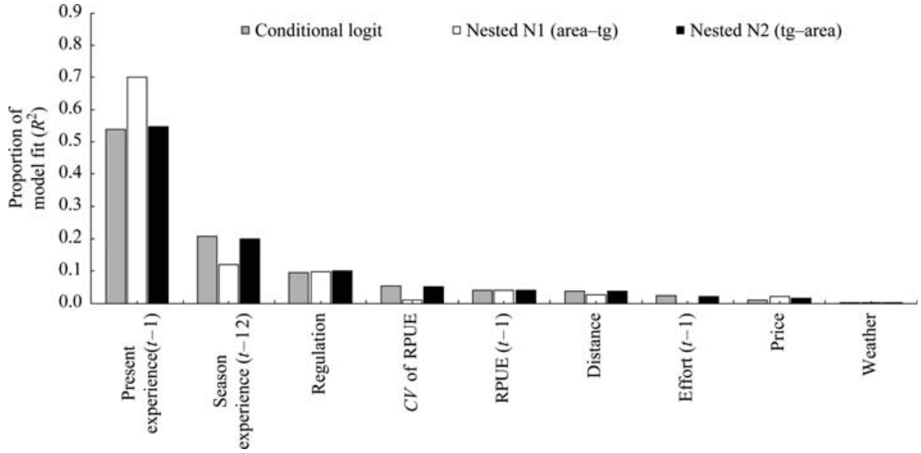

Figure 5. Explanatory power of the individual decision parameter in the choice models. Ordered from left to right based on highest rankings in terms of the psudo-R^2 value.

model fit (Figure 5), whereas the coefficients of present and seasonal experiences contributed to >70% of the variability explained in all three models. A positive sign was found for *CV* of RPUE, indicating that gillnetters preferred alternatives with high variability of the RPUE.

The performance of each of the three models was evaluated by comparing the observed and the predicted levels of effort allocation across target species and fishing grounds over the entire study period (Table 3). Overall, there is a tendency for the models to overestimate effort allocation towards cod and the group other species, and to underestimate effort allocation towards plaice, sole, and turbot. Much larger deviations from observed effort were found when predicting fishing effort among areas, ranging from −60 to 193%. Again, all three models tended to underestimate fishing effort allocation for the areas where mainly sole and turbot are caught (areas 10, 15, and 16).

Alternative test: testing for heterogeneity

A relatively simple test accounting for heterogeneity in fisher choice decision across vessels was followed by allowing parameters to vary across groups of fishers, as in Holland and Sutinen (2000). The population of fishers was divided into groups based on home fishing port. Table 4 shows the estimated parameters where selected characteristics were multiplied by a set of dummy variables corresponding to each fishing port. This allowed the parameters RPUE, *CV* of RPUE, TOT_EFFORT, DISTANCE, and REGULATION to vary across the four main fishing ports. Overall, including this type of flexibility had just a marginal effect on the global fit of the model, but the model output indicated significant differences in behaviour across harbours. Gillnetters from Hirtshals and Hanstholm reacted less to changes in both expected RPUE and total effort. Those vessels reacted positively towards targeting cod in the Skagerrak when the cod ration in the North Sea increased, this being mainly explained by the regulation of cod in the Skagerrak and the North Sea being totally correlated because they deal with a single stock. In contrast, vessels from Hvidesande and Thyborøn reacted negatively, because they rarely target cod in the Skagerrak. For changes in the sole ration, the vessels from Hvidesande and Thyborøn reacted significantly negatively to all other target species compared with actively targeting sole.

Discussion

To improve understanding of the underlying decision processes influencing the choice of métier in a mixed fishery on a trip-by-trip basis, we combined findings from a questionnaire survey on tactical and strategic decisions with quantitative modelling of fisher decision choices based on reported catch-and-effort data. The survey questionnaire identified a number of traditional decision parameters commonly used in discrete choice behavioural studies in fisheries, but also a number of parameters rarely explicitly accounted for, such as fish price, weather, and management regulations.

The work provided an opportunity to compare the estimated importance of each decision parameter in the choice models with how the same parameters were weighted by fishers in their responses to the questionnaire. Correspondence was good, particularly for the highest ranked decision parameters of the survey questionnaire (present and seasonal experiences, and regulation), but both weather and fish price tended to be underestimated in the relative ranking between the defined proxies in the behaviour model. This implies that the main decision parameters were correctly captured, but also illustrates the complexities of constructing a behaviour model based on catch-and-effort data. Below, we address some of the assumptions and technical issues in interpreting the defined decision proxies to improve insight into the mechanisms influencing fisher short-term decisions on choice of métier.

Decision factors

As in several earlier studies (e.g. Holland and Sutinen, 1999; Pradhan and Leung, 2004; Marchal *et al*., 2009), present and seasonal experience/knowledge (short- and long term) were weighted as the most important decision factors for both approaches. In many demersal fisheries, there is a seasonal component driven by differences in the spatio-temporal migration dynamics of target species. For Danish gillnetters, there was an almost constant year-on-year seasonal fishing pattern for plaice, sole, and turbot from 1997 to 2005, but this seasonality was not as clear for cod (Figure 6). Repeatedly selecting the same alternative indicated temporal autocorrelated behaviour that could be explained by state dependence of some of the decision parameters (Smith, 2005). From a management perspective, the current definition applied in both this study and the literature will act as a threshold for individual fishers to react to changes in expected utility (Pradhan and Leung, 2004; Andersen *et al*., 2010), and this may limit the predictive power of the model. That, based on the current defined proxies for past experience, contributes to a threshold component with few dynamics, underscoring the challenge for behavioural modelling studies to capture explicitly the underlying motive as to why fishers tend to follow the same fishing pattern.

Besides the seasonal fishing pattern, several economically driven parameters influenced the mechanisms controlling allocation of fishing effort of Danish gillnetters significantly. In the choice model, the 25% not explained by the seasonal fishing pattern was explained primarily by the level of the seasonal catch ration for cod/sole (∼10%), variability of catch success (∼5%), expected catch success based on information from other fishers (∼4%), distance (∼4%), and price (∼1.5%).

Accounting explicitly for seasonal changes in management regulations has rarely been included in fisher-choice behaviour studies, where the focus has mainly been on evaluating area closures by manipulating the utilities for those alternatives influenced by the closure (e.g. Wilen *et al*., 2002; Hutton *et al*., 2004; Vermard *et al*., 2008). Increases in the cod catch ration motivated gillnetters towards targeting that species, whereas the signal was not as clear for sole. This was surprising, because sole is a valuable species, and it would seem natural therefore that gillnetters would react positively towards targeting sole in situations where the catch ration for that species increased. An explanation for this anomaly could be that in the main fishing period for sole (highly seasonal), the catch ration was virtually unchanged (Figure 3). By the time that increases in the catch ration for sole were announced, it would seem that gillnetters were already harvesting other target species, so the fit was positive for species other than sole, but not for sole. Additionally, the models seem to underestimate sole, and to some extent turbot, choices, most likely explained by the models' limited success at capturing less-represented species with a short seasonal peak (1 month) in the landings. This illustrates some of the complexity in accounting explicitly for management measures in the expected utility, where the same type of regulation may induce different reactions.

Table 3. Predicted vs. observed effort allocated among target species and areas (percentage deviation from observed effort, in terms of days at sea).

Parameter	Conditional	Nested N1	Nested N2	Observed effort
Target species				
Cod	18.9	19.5	20.3	2 796
Other	4.9	3.6	2.4	3 238
Plaice	−0.3	−2.9	−0.8	3 295
Sole	−16.9	−15.1	−13.5	3 393
Turbot	−26.5	−17.0	−26.6	763
Area				
Area 1	192.6	160.4	66.8	153
Area 2	50.3	60.3	73.6	538
Area 3	17.3	18.9	31.1	993
Area 4	−1.6	−0.4	21.2	1 214
Area 5	96.6	91.3	14.6	177
Area 6	129.0	99.6	−4.7	95
Area 7	137.8	126.5	40.5	204
Area 8	−5.9	9.1	−4.8	912
Area 9	1.7	−1.3	−37.3	371
Area 10	−41.9	−31.8	−60.1	388
Area 11	7.7	−2.0	25.2	2 968
Area 12	−7.5	−0.6	−29.7	694
Area 13	24.2	19.3	5.8	509
Area 14	9.6	10.4	−38.3	471
Area 15	−54.3	−49.0	−28.6	2 388
Area 16	−16.0	−14.8	−35.7	1 410

Information from other fishers in terms of catch rates has been included in proxies for expected revenue in behaviour modelling before, and a positive response has been used to confirm economic rational behaviour (Smith, 2000). Danish gillnetters reacted positively to alternatives with higher expected revenue, but explanatory power was low compared with previous studies (Holland and Sutinen, 1999; Hutton *et al*., 2004; Marchal *et al*., 2009). Our findings are, however, in line with the outcome from the survey questionnaire (although that information might be biased through the interviewee being potentially too proud to admit using information from other fishers).

Several choice studies have accounted for the concept of risk when fishers are exposed to uncertainty (e.g. Mistiaen and Strand, 2000; Eggert and Tveteras, 2004). In general, fishers are risk-averse. In contrast, we found a positive response, similar to Holland and Sutinen (1999, 2000), that suggests some risk-seeking behaviour among gillnetters opposite to how the gillnetters were generally characterized in interviews (Christensen and Raakjær, 2006). It is likely that this observed positive risk response reflects the fact that gillnetters react positively to the catch successes of other fishers. Holland (2008) suggested that this positive risk response reflected failure to model the information structure correctly and considered it more as "skewness-loving" than "risk-loving" behaviour.

The gillnet fishery requires limited engine power relative to other demersal fisheries, and this is reflected in the moderate weighting of fuel cost/distance in both the survey questionnaire and the choice models. Although the average gillnet fleet reacted

Table 4. Testing for heterogeneity among major fishing ports, listing the mean decision coefficients from the nested logit (N2) model, with the s.e. in parenthesis (emboldened typeface indicates statistical significance at $p < 0.01$).

Parameter	Hirthals	Hanstholm	Thyborøn	Hvidesande
RPUE ($t-1$)	0.000123 (5.64E−05)	**0.0001538** (2.55E−05)	**0.00018** (1.92E−05)	**0.000318** (1.46E−05)
CV of RPUE ($t-1$)	**0.021200** (1.27E−03)	**0.015000** (9.05E−04)	**0.017200** (9.08E−04)	0.006762 (1.04E−03)
Effort	**−0.005588** (1.48E−03)	**0.000739** (8.70E−04)	**0.003182** (5.14E−04)	**0.002761** (5.48E−04)
Distance	**−0.242300** (5.16E−02)	**−0.396100** (2.69E−02)	**−0.050200** (2.12E−02)	**−0.019900** (2.01E−02)
Regulation				
Cod(S) vs. cod(N)	**0.00186** (0.0003705)	**0.00176** (0.0001965)	**−0.05939** (0.000514)	**−0.00817** (0.0015375)
Cod(N) vs. sole	**0.000249** (0.00494)	**−0.000488** (0.00565)	**−0.000724** (0.000058)	**−0.000765** (0.000071)

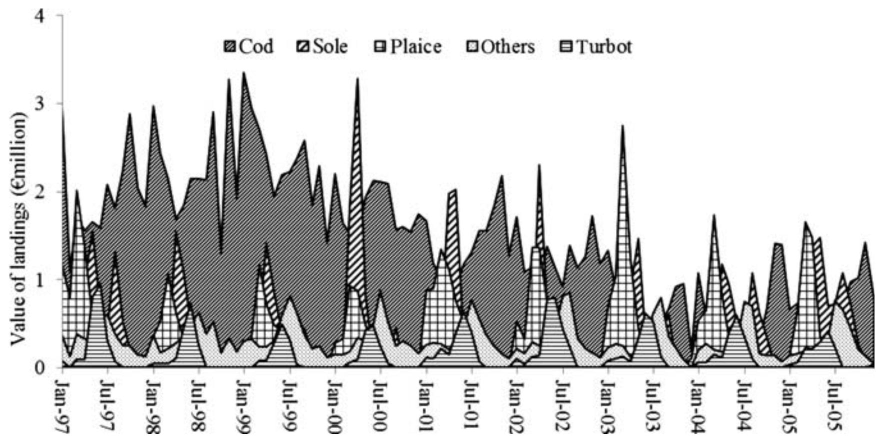

Figure 6. Seasonal landing distributions of the five defined target species from 1997 to 2005 for Danish gillnetters in the North Sea.

negatively to an increase in distance to fishing ground, such findings were only found for two of the four major fishing ports here.

Gillnetters in general depend on relatively calm weather, particularly when hauling their nets, perhaps also because of the small vessel size, which was clearly stated in survey questionnaires (Christensen and Raakjær, 2006). Although Danish gillnetters responded negatively to increased wave heights (except in the nested-N2 model), it only explained <1% of total model fit. The lack of response may be explained by the negative correlation between wave height and total fishing effort on a monthly scale (Pearson's correlation: $\rho = -0.49$), which indicates that the choice model only captured trips fishing in calm weather, mainly in summer, where differences in weather conditions between fishing areas were less obvious. The weather parameter likely influences the choice of whether or not to go fishing rather than the fishing activity itself in terms of target species and area.

The ability to capture tactical choices fully is restricted by the precision level of the available data. Daily catch-and-effort information is given at the spatial resolution of predefined and fixed statistical areas (such as ICES rectangles), regardless of the actual distribution of fishing grounds. High-resolution GPS and vessel monitoring system (VMS) data reveal that several different fishing opportunities (or fishing grounds) can take place within such predefined areas (Branch *et al.*, 2006) and also that the number of fishing grounds can easily exceed several hundred. Standard RUMs have some limitation in spatial resolution in terms of specification of the choice set, because the stability of the maximum likelihood estimation reduces where there are more than 50–100 choices (Hensher *et al.*, 2005). A modified RUM application with detailed and flexible geographic scales in choice setting has been developed by Berman (2007). However, increasing the spatial resolution in choice/métier setting will also increase the number of unrecorded trips to a choice over a period in the data. How to complete missing information in these empty cells can be problematic (Sutinen and Holland, 1999), and the problem will be magnified with increased choice. To minimize the number of choices with no trip records, we reduced the spatial resolution from 84 rectangles to 16 areas, allowing a balance between not losing the spatial dynamics completely against reducing the number of missing cells for model fitting. However, there is no doubt that improving knowledge of the actual fishing grounds (e.g. through high-resolution VMS data) will be beneficial in future modelling studies of short-term fisher behaviour. Similarly, recording more-specific gear riggings and/or intended target fisheries in logbooks at the start of a trip would provide a better basis for modelling fisher tactical choice, as well as the related underlying behavioural processes associated with these decisions.

Heterogeneous response

The variability of questionnaire responses indicated some heterogeneity among Danish gillnetters. Based on the modelling results, Danish North Sea gillnetters can roughly be divided into two groups: (i) vessels from Hirtshals and Hanstholm, fishing mainly in the western part of the Skagerrak, on fishing grounds close to their home port and targeting primarily cod, plaice, and other species, and (ii) vessels from Thyborøn and Hvidesande fishing in a larger area, mainly in the central and southern North Sea, harvesting all five target species/groups. The latter vessels tend to be larger and have a trip duration of several days, whereas vessels from Hirtshals and Hanstholm generally make 1-d trips. The differences in fishing strategies observed may explain why groups of vessels responded differently to several of the decision parameters identified. For example, vessels from Hirtshals were less opportunistic in their response to changes in expected profitability in the resource, and instead continued to fish locally. The heterogeneous responses among gillnetters both in interviews and the behaviour model indicates that Danish gillnetters may also respond differently to changes in management measures, for example, but whether these heterogeneous responses are sufficiently captured through segregation by fishing port is questionable. Although the four fishing ports are geographically distinct, there is overlapping fishing activity among some gillnetters independent of home fishing port, underscoring the need to understand differences in fishing strategies among individual gillnetters better.

Concluding remarks

A key issue in fisheries management is understanding how changes in management regulation may cause changes in effort dynamics, which itself may lead to changes in fishing mortality and the dynamics of individual stocks. Moreover, such changes may change the profitability of some fishing opportunities and hence the whole economic performance of the fishing fleet. An obvious way of validating and evaluating the effects of fisher behaviour on the outcomes of alternative management scenarios is bioeconomic simulation within a management strategy evaluation approach. Andersen *et al*. (2010) implemented a simplified RUM in a bioeconomic simulation modelling framework for the North Sea flatfish fisheries, accounting for relative changes in effort allocation across métiers within a fleet, and a similar framework could be used for Danish gillnetters.

A combination of information directly learned from fishers (survey questionnaire) and empirical modelling of catch-and-effort data is a useful way to improve the predictability of how fishers react to changes in management policy or other external factors. The survey questionnaire used here was originally designed for an anthropological description of Danish fisher tactics and strategies (Christensen and Raakjær, 2006), but we see further opportunities in this type of survey questionnaire to examine fisher behaviour: first, in gathering specific information on fisher choice preferences and of the mechanisms causing heterogeneous responsiveness within a group of fishing vessels, and second in the lesser cost of collecting information directly from fishers relative to the traditional observer trips. Future challenges lie in designing surveys and modelling applications with focus on improving understanding of the underlying motives for fishers to follow the same fishing patterns.

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